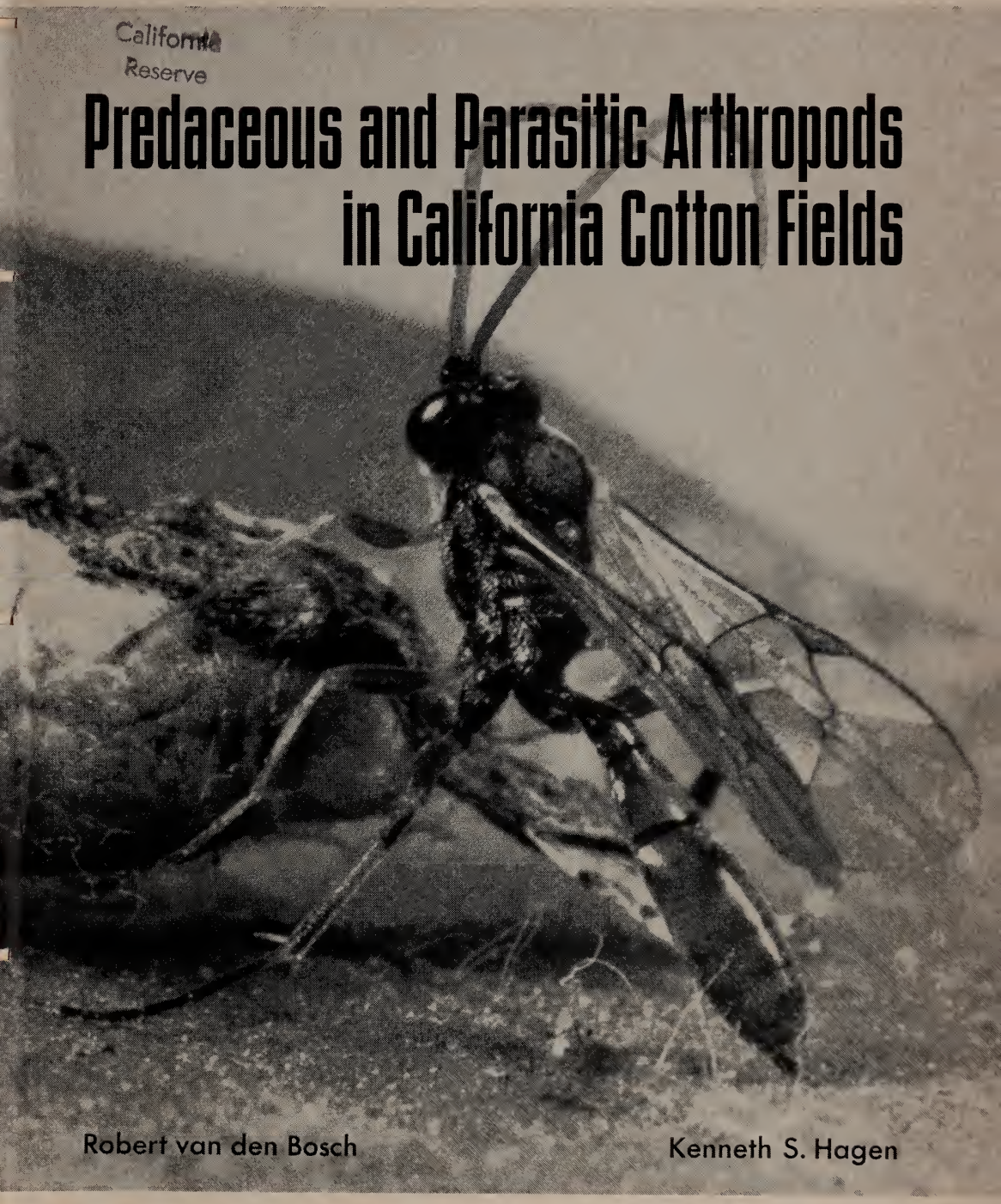
Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

Predaceous and Parasitic Arthropods in California Cotton Fields



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COTTON PRODUCTION in California

... would probably not be economically feasible without the biological control effected by certain beneficial arthropods (insect and insect-like species) that destroy the pests and potential pests. Such control is not entirely effective at all times, of course, and must be supplemented by artificial methods. However, experience has shown that artificial controls used unwisely can interfere with biological control. Current research is seeking materials and methods of artificial control that are highly selective and that will cause minimum disruption of the cotton environment.

Meanwhile, natural enemies of cotton pests are being studied in an effort to increase their usefulness as control agents in this crop.

The beneficial arthropods are of two types: predators and parasites. The predators are more conspicuous in cotton than are the parasites, and their part in biological control is more widely appreciated. In actuality, however, both groups appear to play major roles. This bulletin describes the habits and behavior of a number of predators, discusses parasitism, and lists some common pests of cotton and their parasitic enemies.

THIS BULLETIN PROVIDES INFORMATION ON:

THE AUTHORS:

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Predaceous and Parasitic Arthropods in California Cotton Fields[1]

Robert van den Bosch and Kenneth S. Hagen

An estimated 300 to 350 arthropod (insect and insect-like) species characteristically breed in California cotton or use the fields for more than passing occupancy. This estimate may be conservative; surveys of just the predatory arthropods in Arkansas cotton, made by Whitcomb and Bell (1964),[2] revealed about 600 species to be associated with the crop in that state.

Cotton arthropods are quite diverse in habit; some are pollen or nectar feeders, others are soil dwellers, scavengers, or fungus feeders, many are predaceous or parasitic, and still others, as we know, feed on the vegetative and fruiting parts of the cotton plant.

We estimate that about 20 per cent of the arthropods found in California cotton fall into the plant-feeding category (a total of perhaps 60 to 70 species). We have already identified about 50 plant-feeding species in our surveys, and the presence of another dozen species or more seems likely.

Despite the occurrence of the large complex of potentially damaging insects, California cotton is affected by only about a half-dozen major pests. Furthermore, even these "serious" pests do not cause damage at all times and places. Something in the cotton environment precludes increase to damaging abundance by most of the plant-feeding arthropods, and even limits the ravages of the few species that do cause damage. Of course, physical factors (climate, cultural practices, soil condition, etc.) have much to do with restricting the abundance and damage of arthropods. Furthermore, for certain species, cotton is nutritionally inadequate and thus limits reproduction. But despite these limiting factors, many more plant-feeding arthropods probably would reach severely damaging abundance if it were not for biological control, particularly that effected by predators and parasites.

Insect-destroying arthropods occur in great abundance and variety in California cotton fields. It is probably safe to say that every one of the key pest species is attacked by a complex of a half-dozen or more natural enemies. (See, for example, the list of parasites of lepidopterous pests on pages 24–26.) These beneficial species, individually and in totality, have a great repressive effect on populations of pest species. Figure 1, for example, shows the effect of just a single parasite species, *Trichogramma semifumatum* Perk., on its host the cotton bollworm, *Heliothis zea* (Boddie).

It is doubtful whether cotton production would be economically feasible in the

[1] Submitted for publication January 27, 1965.

[2] See "Literature Cited" for citations referred to in the text by author and date. For general information, see the list of general references, page 27.

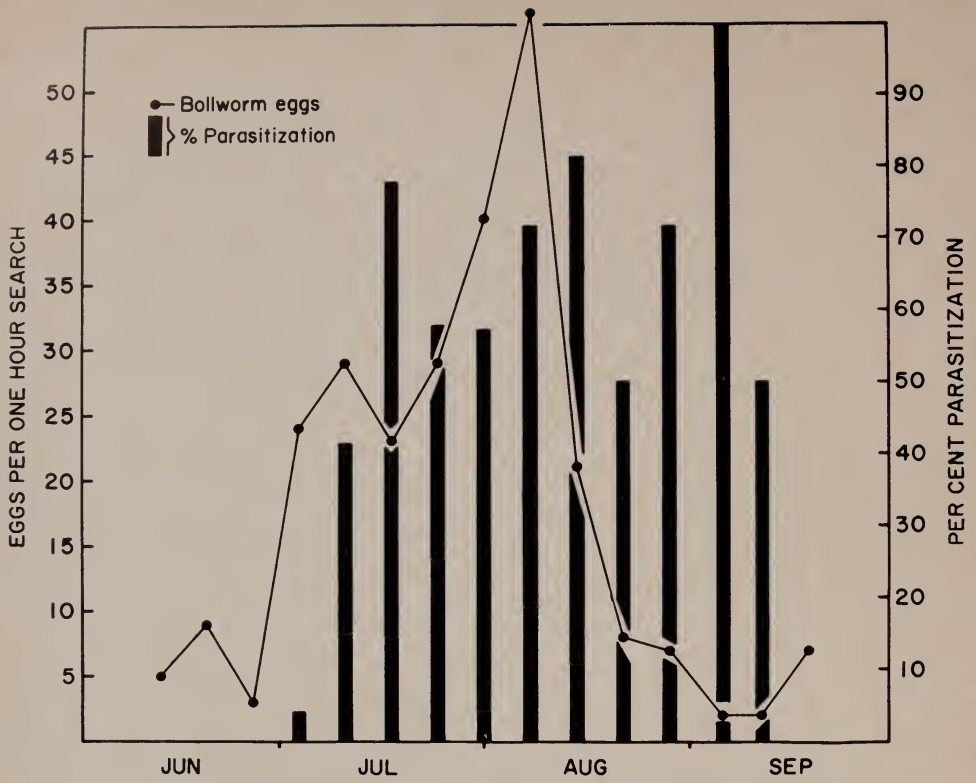


Fig. 1. Parasitization of bollworm eggs by *Trichogramma semifumatum* Perk. in a commercial cotton field, Coachella Valley, 1962.

state without naturally-occurring biological control. On the other hand, biological control is not always fully effective, and frequently must be supplemented by artificial control methods. Unwise, untimely, or indiscriminate use of chemical insecticides can interfere with biological control, engendering new problems as great or greater than the original ones. As a result, there is a growing awareness that the most effective pest control in cotton entails maximum use of biological control plus artificial controls utilized in a truly augmentative way. Our present efforts in seeking artificial controls are directed toward finding materials and methods that are highly selective, with a minimum of disruption to the cotton environment. Meanwhile there is an increased effort to gain more knowledge of the natural enemies of cotton pests and to enhance the general efficacy of biological control agents in this crop.

This bulletin has been written to provide a better understanding of the more conspicuous predatory and parasitic arthropods occurring in cotton.

WHAT ARE PREDATORS AND PARASITES?

Beneficial arthropods in cotton are of two major types: predators and parasites.

Predatory forms are found in a number of arthropod groups. A predator seizes, overpowers or immobilizes its prey and then either consumes it entirely or sucks

it dry of its body fluids. The individual predator can destroy many prey. For example, during its lifetime a single lady beetle may consume several thousand aphids.

Most of the parasites are either fly or wasp species that are parasitic in their larval stages and free-living as adults. An individual parasite larva usually completes its development in or upon a single victim (host). The efficiency of a particular parasite species may depend on searching ability of the female, effective reproductive capacity, sex ratio, synchrony with the host species, availability of nutrients in the environment, and so forth. Any one or a combination of these factors will affect the efficacy and even the survival of a species in a given environment.

PREDATORS

Since predators are more conspicuous than parasites in cotton, their role in biological pest control is more generally appreciated. However, the relative importance of the two natural-enemy groups is not well known to entomologists and one assumes that in actuality they are both of great importance.

Because of the conspicuousness, diversity, and abundance of predators, the following pages are devoted largely to describing certain species of this natural-enemy group and discussing their habits and behavior.[3]

Green Lacewings

(*Chrysopa* spp.)

Green lacewings are among the most important beneficial insects in cotton. Two species are of major importance in cotton in California: *Chrysopa carnea* Stephens (= *C. californica* Coq. and *C. plorabunda* Fitch) and *C. nigricornis* Burm. (= *C. majuscula* Banks). The former is generally the more abundant. The adults are medium-sized (½ to ¾ inch long), green, yellowish-green, or sometimes brownish, with golden eyes and delicate, netted wings (fig. 2A). They have a characteristic fluttering flight, and sometimes rise from cotton in large numbers when the plants are disturbed.

Adults of *C. carnea* are not predaceous, but feed on honeydews and sweet plant exudations. Adults of *C. nigricornis* are predaceous.

The stalked eggs of green lacewings are deposited rather randomly over the plant. Eggs of *C. carnea* are deposited singly, whereas those of *C. nigricornis* are deposited in clusters (fig. 2B). The pale green eggs, which are ovoid in shape, darken just before hatching.

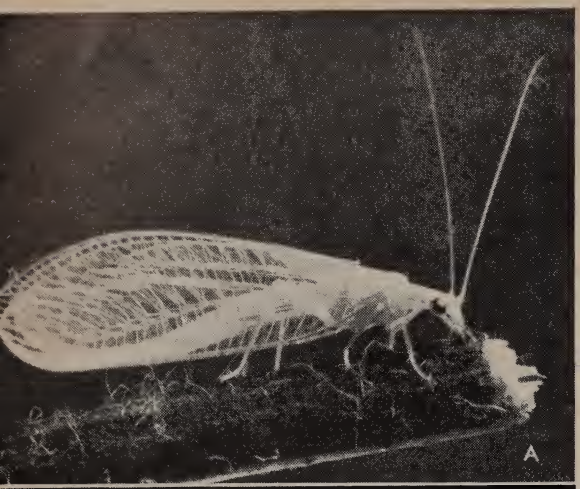
The larvae attain a maximum length of about ⅜ inch, are alligator-shaped, and mottled gray or yellowish-gray (fig. 2C). They are active searchers, particularly at night, and move continually about the cotton plants. The larva seizes its soft-bodied prey, punctures it by means of long, sickle-like mandibles, and withdraws body fluids.

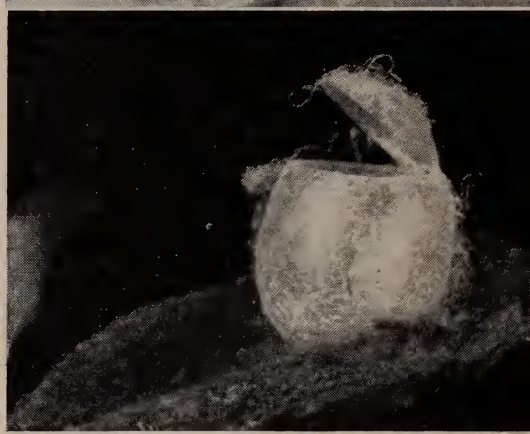
When mature, the larva seeks some protected place, and spins a globular, parchment-like cocoon, in which it transforms into a pupa (fig. 2D). Eventually the pupa changes to the adult, which emerges by cutting and forcing a circular cap off the cocoon.

Chrysopa carnea overwinters as an adult, whereas *C. nigricornis*, like many other species, overwinters in the cocoon stage.

Green lacewings become increasingly important in cotton fields from midseason

[3] Measurements accompanying arthropod stages illustrated in this bulletin reflect size ranges of samples in hand and not absolute size ranges of the species. (1 inch = 25.4 mm.)





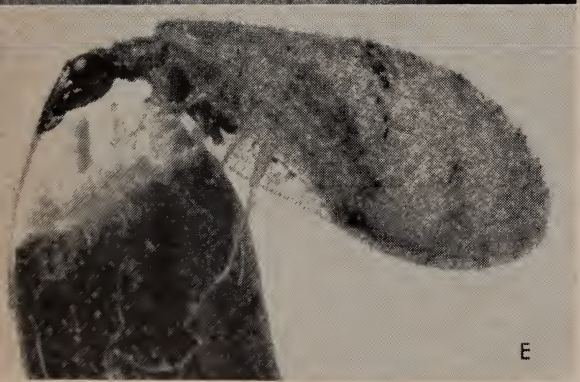


Fig. 2. Lacewings. (A) Adult of green lacewing, *Chrysopa carnea* Stephens; actual length, 15–20 mm. (B) Eggs of *C. nigricornis* Burm.; actual length of egg, 0.5 mm.; egg stalk, 5–10 mm. (C) Larva of *C. carnea* Stephens; actual length when mature, 6–10 mm. (D) Cocoon of *Chrysopa* sp.; actual diameter, 2.75 mm. (E) Adult of a brown lacewing, *Hemerobius* sp.; actual length, 6 mm. (Photos of adults and eggs by Kenneth Middleham; photo of larva and cocoon by Frank Skinner.)

on. They are rather indiscriminate feeders, destroying such soft-bodied hosts as spider mites, bollworm larvae, aphids, and whiteflies, as well as insect eggs. The small larvae feed upon spider mites to a much greater extent than do the older larvae. Green lacewing larvae are quite tolerant of certain insecticides and at times are encountered in goodly numbers in fields that have been chemically treated.

Taxonomy: Bickley and MacLeod (1956), Bram and Bickley (1963)

Biology: Smith (1922), Killington (1936, 1937), Balduf (1939), Clancy (1946*b*), Hagen (1950),

Principi (1956), Burke and Martin (1956)

Brown Lacewings

(*Hemerobius* spp.)

Brown lacewings, particularly *Hemerobius* spp., are sometimes found in cotton fields, but never rival green lacewings in abundance. The adults are smaller than those of *Chrysopa,* and are brownish in color (fig. 2E). The eggs are not stalked and are deposited horizontally on the leaves. The brown lacewing egg resembles those of certain hover flies, but has a distinct projecting knob at one end. Superficially the larvae are similar to those of green lacewings, but living specimens can be distinguished by their characteristic "head-wagging" habit.

Taxonomy: Carpenter (1940)

Biology: Ashmead (1894), Smith (1923), Killington (1936, 1937), Balduf (1939), Wegenek (1950)

Minute Pirate Bug

(*Orius tristicolor* (White))

The adult *Orius* is a black-and-white, tiny (less than 1/8 inch long), somewhat flattened and ovoid, active insect (fig. 3A). It is armed with a prominent beak, with which it pierces soft-bodied prey. The eggs of the minute pirate bug are deposited in soft plant tissue. Only the circular, concave egg caps protrude above the surface (fig. 3B), and thus the eggs are rarely seen by the casual observer. *Orius* nymphs (immature stages) commonly are yellowish, but may be amber or brownish. In the later stages, they are generally of the same shape as the adults, and are equally active (fig. 3C).

Orius adults and nymphs may be found on all aerial plant parts, but occur most commonly in terminal growth and flowers where they are associated with their favored hosts, thrips. At times, however, they will be found in abundance on the undersides of leaves, feeding on spider mite colonies.

The minute pirate bug is one of the

Fig. 3. The minute pirate bug, *Orius tristicolor* (White). (A) Adult; actual length, 1.8–2.1 mm. (B) Eggs inserted in plant tissue; actual diameter of egg caps, approximately 0.25 mm. (C) Nymph feeding on an aphid; actual length, 1 mm. (Photos of adult and nymph by Kenneth Middleham; photo of eggs by Frank Skinner.)

first of the beneficial insects to appear in abundance in cotton fields each year. The adults are attracted by the thrips and spider mite populations that frequently develop when the plants are still in the seedling stage.

Although *Orius* is commonly associated with thrips, it also attacks a variety of other pest species. As mentioned, spider mites are often attacked, as are the eggs and newly hatched larvae of the cotton bollworm and other moth species, and such soft-bodied prey as aphids and whiteflies. At times *Orius* inserts its beak into plant tissue, apparently to take moisture, but there is no evidence that this activity is harmful to the plant.

Of the beneficial insects, *Orius* appears to be one of those harmed least by insecticidal treatments in cotton fields. This perhaps results from its frequenting protected places, where it is not readily contacted by the insecticides, rather than from a true tolerance of these materials.

Taxonomy: Kelton (1963)

Biology: Barber (1936), Ewing and Ivy (1943), Knowlton (1944), Iglinsky and Rainwater (1950), Collyer (1953), Sands (1957), Carayon and Steffan (1959)

Big-eyed Bugs

(*Geocoris* spp.)

Two big-eyed bug species are important in California cotton: *Geocoris pallens* Stål and G. *punctipes* (Say). Both species are found in all cotton-growing areas; *G. pallens* predominates in the San Joaquin Valley, whereas *G. punctipes* is more abundant in the Colorado Desert valleys.

Big-eyed bug adults range from about 1/8 to 1/4 inch in length, *G. punctipes* being

Fig. 4. Big-eyed bugs. (A) Adult of *Geocoris punctipes* (Say); actual length, 3–4 mm. (B) Adult of *G. punctipes* feeding on a leafhopper. (C) Eggs of *Geocoris* sp.; actual length, approximately .01 mm. (D) Nymph of *G. punctipes;* actual length, 2–2.5 mm. (Photos by Kenneth Middleham.)

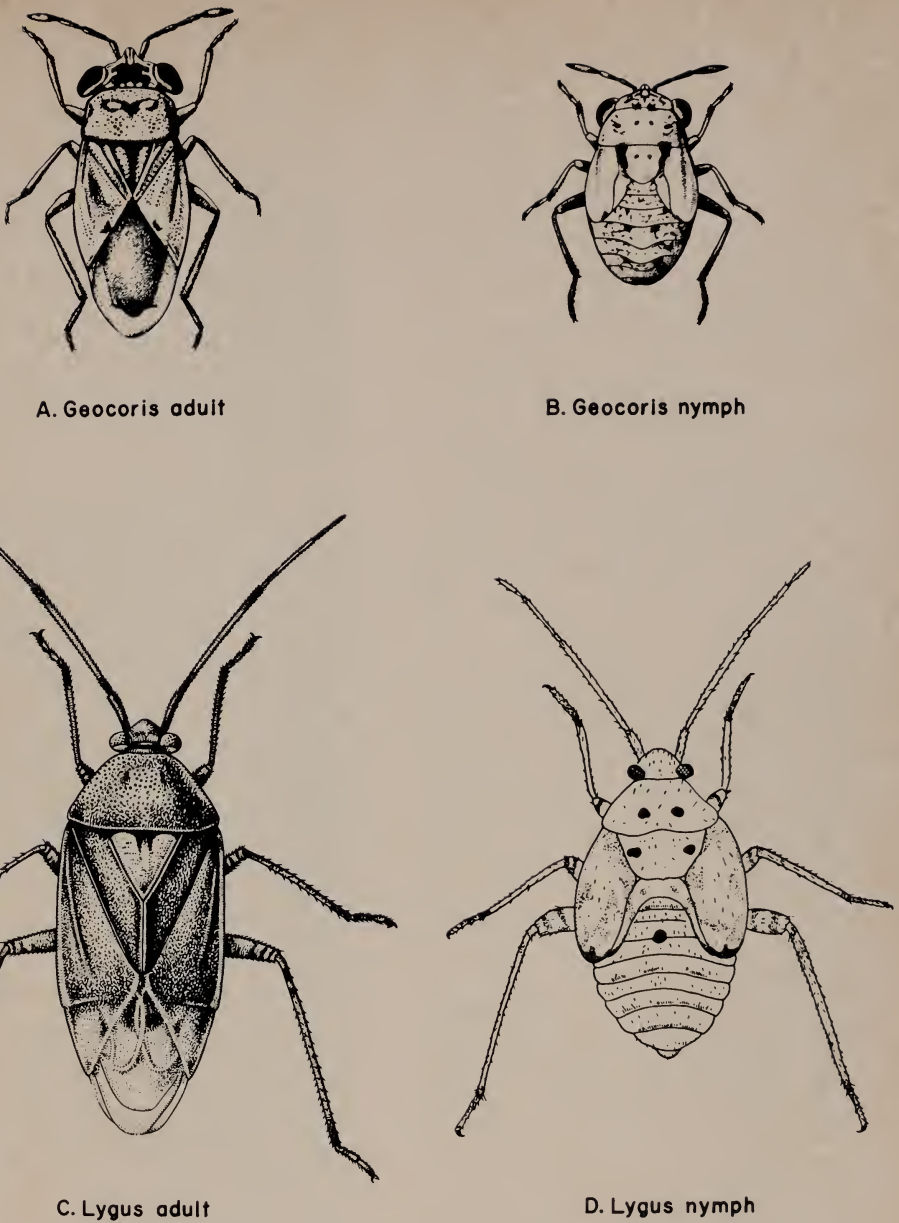


Fig. 5. Comparison of the lygus bug, *Lygus hesperus* Knight, with the big-eyed bug, *Geocoris pallens* Stål. (Drawings of *Lygus* adult and *Geocoris* adult and nymph by Celeste Green; *Lygus* nymph by C. F. Lagace.)

distinctly the larger (fig. 4A, B). Coloration of the adults ranges from gray through tan to black. *G. punctipes* is a grayish species; *G. pallens* is most commonly buff-colored although some individuals are black.

The eggs of *Geocoris* are deposited singly, frequently in the terminal growth, but sometimes conspicuously in spider mite colonies on the undersides of leaves. The egg is subcylindrical, grayish-white, with projecting slender processes on the

anterior end. Conspicuous red eye spots are visible through the egg shell just before hatching (fig. 4C). The eggs are frequently parasitized by a wasp (*Telenomus* sp.), which turns them black.

Geocoris nymphs superficially resemble the adults, but are wingless and more robust (fig. 4D). Both adults and nymphs move rapidly, and tumble readily from the plants when disturbed.

The species of big-eyed bugs often occur in abundance in cotton early in the season, appearing in the fields soon after plants emerge. They reach peak abundance in midsummer, and thereafter seem to decrease in numbers. Their late-summer decrease may be due in part to heavy egg parasitization and possibly to reproductive diapause in the females (van den Bosch and Hagen, unpublished data).

Big-eyed bugs frequently become extremely abundant and at times are the most conspicuous insects in cotton. They are important predators of a number of pests, ranking as primary enemies of lygus bugs, leafhoppers, spider mites, and probably the smaller larvae of the cotton bollworm. They also feed on eggs of certain pests. *Geocoris* will take moisture from the cotton plant, but again this habit appears to be harmless.

Although generally smaller and quite distinct in appearance from *Lygus*, big-eyed bugs are often mistaken for *Lygus*. Chemical treatments have been applied needlessly because of this misidentification. Careful comparison of *Lygus* and *Geocoris* adults shows the former to be larger and to have distinctly longer antennae, a narrower head, and smaller eyes. Striking color differences also occur between the two, *Lygus* being more greenish. Figure 5 shows the differences between adult and nymphal stages of *Lygus* and *Geocoris*.

Taxonomy: Usinger (1936)
Biology: York (1944), Sweet (1960)

Damsel Bugs

(*Nabis* spp.)

Two important species of *Nabis* occur in California cotton fields: *Nabis americoferus* Carayon (=*ferus* Harris, 1928), occurring throughout the cotton-growing areas; and *Nabis alternatus* Parsh., abundant in the southern desert valleys.

Adults of both species are slender, tan or grayish, about ⅜ to ½ inch long (fig. 6A). The thorax tapers anteriorly, and the narrow head is armed with a long beak. The forelegs are somewhat raptorial (developed for seizing prey) but are not grossly swollen or spined. *Nabis* adults move rapidly, and tumble from the plants when disturbed.

Nabis eggs are deposited in soft plant tissue with only the flat circular caps protruding above the surface (fig. 6B). The circular egg caps can be readily distinguished from those of *Lygus* eggs, which are narrowly oval (fig. 6C).

Nabis nymphs closely resemble the adults except that they are smaller, and lack wings (fig. 6D). The smallest nymphs appear somewhat sway-backed.

Damsel bugs generally do not become abundant in cotton until midseason, but are often common in the fields from that time on. The bugs feed on a variety of hosts, including aphids, leafhoppers, lygus bugs, spider mites, and small caterpillars.

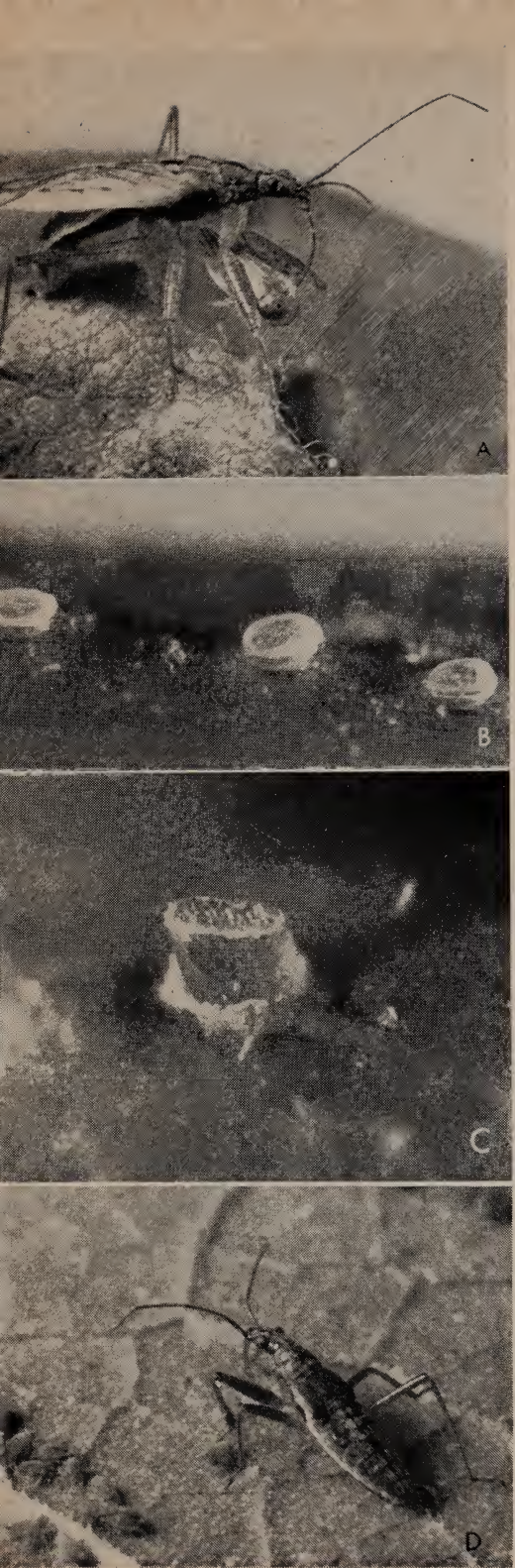
Taxonomy: Harris (1928), Werner and Butler (1957), Carayon (1961)
Biology: Taylor (1949), Werner and Butler (1957)

Assassin Bugs

(*Zelus* spp.)

The assassin bug most commonly found in California cotton is *Zelus renardii* Kol., although *Z. socius* (Uhl.) is also encountered.

The *Z. renardii* adult is a moderately slender insect about ½ inch long, green and red, and armed with a strong beak (fig. 7A).



Z. renardii lays dark brown, white-capped eggs (fig. 7B) in tight clusters at scattered places on the cotton plant. The eggs are not embedded in plant tissue. The nymph superficially resembles the adult, but of course is smaller and wingless (fig. 7C).

Assassin bugs are rather general feeders, preying upon both beneficial and plant-feeding insects. However, they are never abundant and apparently are not of major importance in biological control of any cotton pest.

Taxonomy: Readio (1927)

Biology: Readio (1927), Swezey (1936), Werner and Butler (1957), Young and Sifuentes (1959)

Spined Soldier Bugs

(*Sinea* spp.)

Spined soldier bugs are rather closely related to the assassin bugs, and pass through similar developmental stages. Three *Sinea* species are important in California cotton: *Sinea diadema* (Fabr.), *S. confusa* Caud., and *S. complexa* Caud. *S. diadema* occurs over all cotton-growing areas; *S. confusa* and *S. complexa* are desert species.

Adults are moderately robust, sluggish, medium-sized (½ inch long), and buff or brownish (fig. 8). They are characterized by spiny, somewhat swollen, raptorial forelegs and spined thoraces. The nymphs resemble the adults in appearance and actions, but are wingless and distinctly sway-backed.

Fig. 6. (A) Adult of the damsel bug, *Nabis americoferus* Carayon, feeding on a leafhopper; actual length, 8 mm. (B) Eggs of *Nabis* sp., with only the caps visible above plant surface; actual diameter of egg cap, 0.3–0.4 mm. (C) Egg of *Lygus hesperus*, with only the cap and a fraction of the egg body visible above the plant surface. Note more oval shape of the egg cap as compared with that of *Nabis*. Actual lengthwise diameter of cap, 0.48 mm. (D) Nymph of *Nabis* sp. in an aphid colony; actual length of nymph, 6 mm. (Photo of adult by Kenneth Middleham; photo of eggs and nymph by Frank Skinner.)

Fig. 7. Above: the assassin bug, *Zelus renardii* Kol. (A) Adult; actual length 10–13 mm. (B) Egg mass; actual length of an egg, approximately 1.7 mm. (C) Nymph; actual length, up to 12 mm. (Photos by Kenneth Middleham.)

Fig. 8. Right: adult female of the spined soldier bug, *Sinea diadema* (Fabr.), with freshly deposited eggs. Actual length of adult, 12 mm. (Photo by Kenneth Middleham.)

The characteristically ornamented eggs of *Sinea* are deposited in tight clusters on the surfaces of the leaves and stems of the cotton plants (fig. 8).

Spined soldier bugs occur in greatest abundance from midseason on. These rather indiscriminate feeders unquestionably contribute to the overall environmental pressure exerted against a variety of cotton pests, but in themselves do not appear to be of great importance.

Taxonomy: Readio (1927), Werner and Butler (1957)

Biology: Ashmead (1894), Readio (1924, 1927), Balduf and Slater (1943), Balduf (1948, 1950), Werner and Butler (1957)

Collops Beetles

(*Collops* spp.)

Two important *Collops* species are found in California cotton fields: *Collops vittatus* (Say), in the San Joaquin Valley; *Collops marginellus* LeConte, in the Colorado Desert valleys. Adults of both species are small, active, blue-and-red beetles (fig. 9A). The red of *C. vittatus* is brighter than that of *C. marginellus*, and the blue areas of its wing covers have a more metallic cast.

Collops females generally lay their eggs

in ground litter, which is also the normal larval habitat. However, *C. vittatus* sometimes deposits its pinkish-orange, spindle-shaped eggs (fig. 9B) in the cotton terminals, and the smaller larvae may be found in the upper parts of the plants. As they increase in size, however, these larvae move off the plants into the ground litter. *Collops* larvae reach a maximum length of about ⅜ inch and range in color from pink through orange-red to purplish-red. The larva bears a characteristic pincer-like structure (opposing urogomphi) at the tip of the abdomen (fig. 9C). Pupation occurs in soil, where the naked pupa (fig. 9D) is formed at a depth of about ½ inch.

Collops beetle adults may be found in cotton fields at any time during the growing season, but reach greatest abundance from midseason on. At times they become extremely abundant. *Collops* adults feed on a variety of insect hosts, attacking eggs, larvae, nymphs, pupae, or adults, depending on the species. The larvae are also predaceous.

Collops marginellus has been reported as a major predator of stink bug (*Euschistus*) eggs, and both *C. marginellus* and *C. vittatus* feed on moth eggs. *Collops* beetles are also known to feed on aphids, spider mites, and moth and butterfly larvae.

Taxonomy: Fall (1912), Marshall (1951, 1952)

Biology: Balduf (1935), Clancy 1946*a*), Walker (1957), Nielson and Henderson (1959

Lady Beetles

(*Coccinellidae*)

The most conspicuous lady beetles in cotton are the larger aphid-feeding species.

Fig. 9. Collops beetle. (A) Adult female of *Collops vittatus* (Say); actual length, 5–6 mm. (B) Eggs of *C. vittatus;* actual length, 0.76–1.1 mm. (C) larva of *Collops* sp.; actual length, 6–8 mm. (D) Pupa of *Collops* sp.; actual length, 5–6 mm. (Photos of adult, larva, and pupa by Kenneth Middleham; photo of eggs by Frank Skinner.)

Fig. 10. Lady beetles. (A) Adult of the convergent lady beetle, *Hippodamia convergens* Guér., feeding on an aphid; actual length of beetle, 6–8 mm. (B) Lady beetle eggs; actual length, 1.4 mm.

This group includes *Hippodamia convergens* Guér., *H. quinquesignata punctulata* LeConte, *H. parenthesis* (Say), *Coccinella novemnotata franciscana* Casey, *Olla abdominalis* (Say), and *Cycloneda sanguinea* (L.). *Paranaemia vittegera* (Muls.), a purplish-red, black-striped species, which feeds mainly on moth eggs, is also seen at times in the fields.

In the Colorado Desert valleys, only *H. convergens* is of major significance in cotton, although *O. abdominalis* and *C. sanguinea* are encountered at times. The aphid-feeding lady beetles occur as a complex of species in the San Joaquin Valley, with *H. convergens* and *H. quinquesignata punctulata* perhaps most abundant.

With the exception of *O. abdominalis*, which has two color forms (one grayish and the other shiny black marked with two large red spots), all the aphid-feeding lady beetles mentioned above are red or reddish-orange, marked with black and white. Adults of these lady beetle species measure about ¼ inch in length (fig. 10A).

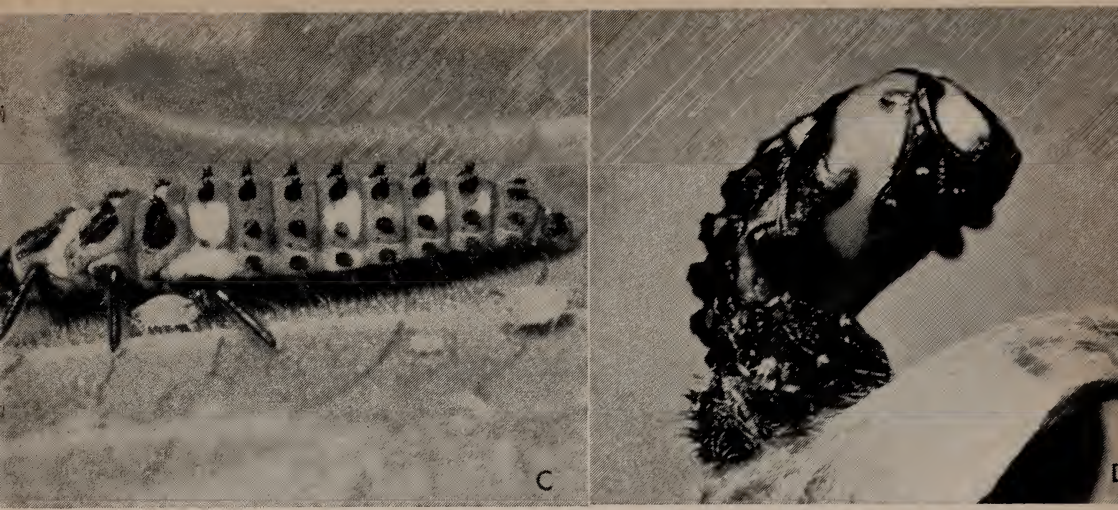
The yellowish-orange, spindle-shaped eggs are deposited in compact clusters on cotton stems and foliage or on ground litter (fig. 10B). The larvae of most species are blue-black and orange. Those of *O. abdominalis* and *C. novemnotata franciscana* are light grayish.

Lady beetle larvae are alligator-shaped, but do not have the long, sickle-like mandibles and are less tapered than are green lacewing larvae (fig. 10C). They move fairly rapidly over the plant and are voracious feeders.

The somewhat hemispherical orange-and-black pupae are formed on the leaves and stems of plants or on ground litter or clods (fig. 10D).

Aphid-feeding lady beetles may be encountered in cotton at almost any time during the growing season. In the seedling period, adults are attracted to the scattered aphid colonies that frequently appear at this time. During midseason, when aphids are absent from the fields, the adult beetles feed principally on plant exudations or pollen and are not extensively predatory. In the fall, when cotton aphid infestations increase once more, the beetles again become actively predatory, and reproduce. (The mass release of lady beetles as a pest-control technique is discussed on page 26.)

In addition to the more conspicuous



(C) Larva of *Hippodamia* sp.; actual length, 7–10 mm. (D) Pupa of *Hippodamia* sp.; actual length, 6 mm. (Photo of adult by Kenneth Middleham; photos of eggs, larva, and pupa by Frank Skinner.)

aphid-feeding lady beetles discussed above, certain smaller species belonging to the genera *Scymnus* and *Hyperaspis* may, on occasion, occur in cotton fields. The adults of these aphid feeders are dull black or shiny black marked with orange or yellow. *Scymnus* is hairy and dullish black; *Hyperaspis* is shiny and without hair. The larvae are usually covered with white waxy material which gives them a mealybug-like appearance.

Taxonomy: Casey (1899), Gage (1920), Dobzhansky (1931, 1941), Timberlake (1943), Chapin (1946), Brown (1962)

Biology: Clausen (1916), Essig (1920), Conrad (1959), Hodek (1958, 1960), Kaddou (1960), Hagen (1962)

Spider Mite-feeding Lady Beetle

(*Stethorus picipes* Casey)

Apparently only one spider mite-feeding lady beetle species, *Stethorus picipes*, is found in California cotton. This species is quite distinct from the aphid-feeding species just discussed. The adult is jet black, with inconspicuous, silvery hairs. It is about the size of a pinhead (fig. 11A). Adults are commonly seen in the spider mite colonies as quiescent, black specks. However, they move rather rapidly when disturbed.

The tiny, spindle-shaped eggs are deposited singly in the mite colonies. The larvae are dark brown or nearly black, and are clothed with hairs which give them a velvety appearance (fig. 11B).

When the larvae are mature, they transform to pupae of a dark mahogany color. The naked pupae are also found in spider mite colonies, attached by their anal ends to plant surfaces (fig. 11C).

The presence of *S. picipes* in cotton fields is correlated with spider mite infestations. Usually *S. picipes* does not become abundant until after the host infestations have become moderately heavy. This beetle aids in reducing such infestations, but is not considered important in maintaining spider mite populations at low densities.

Taxonomy: Kapur (1948), Brown (1950)

Biology: Fleschner (1950), Putman (1956)

Fungus-feeding Lady Beetles

Occasionally, small, mottled, whitish lady beetles may be observed in cotton. These

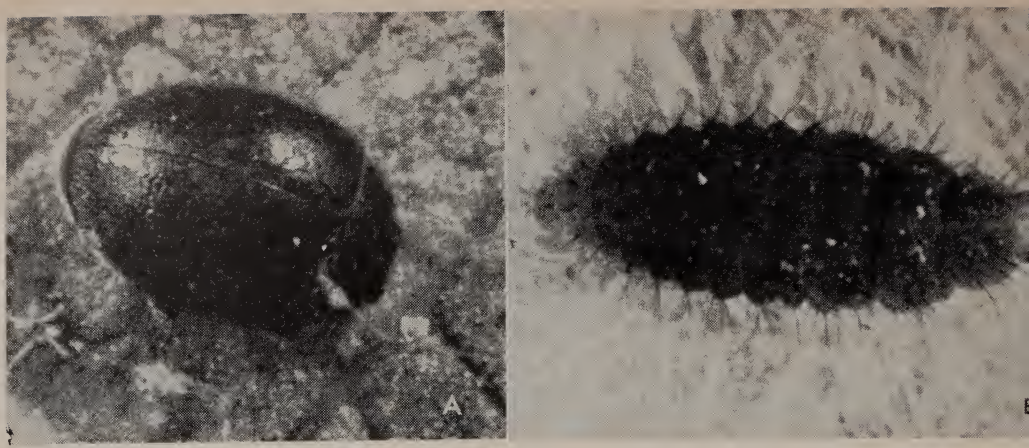


Fig. 11. Spider mite-feeding lady beetle, *Stethorus picipes* Casey. (A) Adult; actual length, 1–1.3 mm. (B) Larva; actual length, 1–1.3 mm.

belong to the genus *Psyllobora*, and gain their nutrition from molds and similar fungi. They are not known to feed on any insect species and thus do not play a role in biological control of cotton pests.

Taxonomy: Timberlake (1943)

Biology: Little is known about *Psyllobora*.

Notoxus Beetle

(*Notoxus calcaratus* Horn)

The small ant-like beetle, *Notoxus calcaratus* Horn, is often very abundant in California cotton fields. *Notoxus* beetles are yellowish-brown with black bands. Close inspection reveals a prominent horn-like projection extending from the thorax over the head.

The feeding habits of the *Notoxus* beetle are not well understood, but the beetles are known to feed on plant exudates and they perhaps also feed on small insects. They do not feed directly on the cotton plant.

The larvae live in sandy soil.

Taxonomy: Casey (1895), Hagen (1948)

Biology: Essig (1926), Smith (1942)

Hover Flies

(Syrphidae)

Various beneficial hover fly species occur in cotton. The adults, about ¼ to ½ inch long, are normally marked on the abdomen with yellow, white or black bands (fig. 12A). They fly swiftly and have a characteristic hovering ability. The adults are not predaceous, but feed on pollen, nectar, and honeydew.

The hover fly eggs are chalky white, often with faint longitudinal ridges and a knob within an indentation at one end

Fig. 12. Hover fly. (A) Adult of *Mesograpta* sp.; actual length, 5–6 mm. (B) Egg, species unknown; actual length, 0.9 mm. (C) Larva, species unknown; actual length, 7–8 mm.

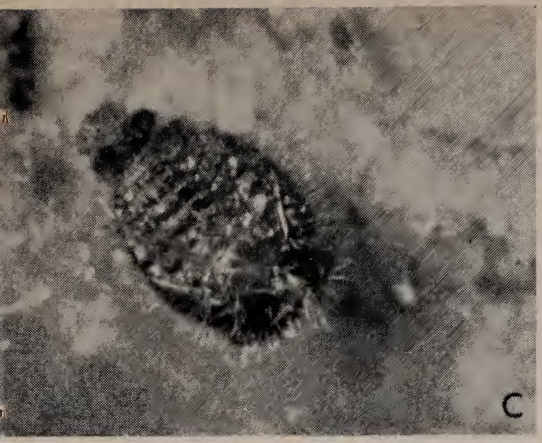


Fig. 11 (cont.) (C) Pupa; actual length, 1.2 mm. (Photos by Kenneth Middleham.)

(fig. 12B). The eggs are deposited horizontally on the plant surface and are usually found in aphid colonies.

The larvae are blind, slug-like in appearance, green, brown, or purplish, and characteristically tapered toward the anterior end (fig. 12C). Hover fly larvae prey on aphids. They are voracious feeders, armed with strong black mouth hooks with which they seize their prey and through which they withdraw the aphid's body fluids. Black oily smears of excrement on plant leaves are typical signs of the presence or recent occurrence of hover fly larvae.

The larvae may reach a length of about ½ inch immediately before pupation. The parchment-like puparia (pupal structures) are elliptical or somewhat tear-shaped, and may be green, grayish, or brownish (fig. 12D). The puparia are sometimes formed on cotton foliage, but pupation generally occurs in ground litter.

Hover flies occur in cotton over much of the growing season, but reproduce most actively in the fall, when the heaviest aphid populations develop. Parasite attack on hover fly larvae and puparia is so heavy at times that the effectiveness of these predators is greatly reduced.

Taxonomy: Curran (1934), Heiss (1938), Hull (1949), Hennig (1952), Důsek and Láska (1959)

Biology: Metcalf (1913), Davidson (1916), Campbell and Davidson (1924), Bhatia (1939), Kamal (1939), Schneider (1948, 1951, 1958), Weems (1954), Butler and Werner (1957)

Six-spotted Thrips

(*Scolothrips sexmaculatus* (Perg.))

Adults of the six-spotted thrips, *Scolothrips sexmaculatus*, are tiny yellowish insects that are distinguished from all other thrips in cotton by three dark spots on each forewing (fig. 13). Both the adult and larval stages of *Scolothrips* are predaceous upon spider mites.

The capless, kidney-shaped eggs are deposited in soft plant tissue. The larvae are whitish or yellowish, and approach the size of adults when mature. However, they are wingless and without dark markings. Pupation occurs on the leaf surface in the mite colonies. The pupa is yellowish and more robust than is the larva.

Fig. 12 (cont.) (D) Puparium, species unknown: actual length, 10 mm. (Photo of adult by Kenneth Middleham; photos of the egg, larva, and puparium by Frank Skinner.)

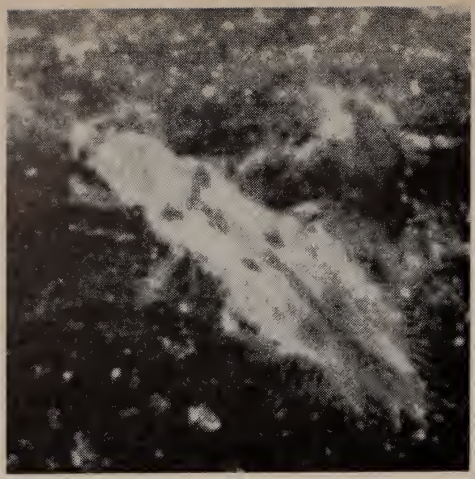


Fig. 13. The predaceous thrips, *Scolothrips sexmaculatus* (Perg.). Actual length, approximately 0.8 mm. (Photo by Kenneth Middleham.)

Scolothrips abundance is correlated with spider mite abundance. The thrips usually does not become conspicuous until spider mite populations have reached moderate proportions.

Taxonomy and Biology: Bailey (1939)

Predatory Mites of the Family Phytoseiidae

Plant-feeding spider mites are at times attacked by tiny, tan, fast-moving mites of the family Phytoseiidae. These beneficial mites are larger than plant-feeding spider mites, and have a flatter, pear-shaped body and longer legs. The eggs are colorless and broadly oval, whereas the eggs of the plant-feeding spider mites are spherical and frequently colored or opaque.

Cotton apparently is not a favorable habitat for the phytoseiids, and they do not seem to play an important role in spider mite control.

Taxonomy: Chant (1959), Schuster and Pritchard (1963), Muma (1963)

Biology: Huffaker (1958), Chant (1961), Leigh (1963)

Miscellaneous Predators

The species discussed in this paper represent only a few of the more conspicuous predatory forms occurring in the cotton arthropod complex. Certain other species become abundant at times. Perhaps the most striking of these are the praying mantids, one species of which is the largest predatory arthropod in California cotton (fig. 14A). Mantids are general feeders, however, and never attain great abundance. It is questionable whether they contribute significantly to the biological control of any pest species.

A

B

Fig. 15. Spiders. (A) Crab spider (Thomisidae); actual length, 8.4–12.8 mm. (B) Wolf spider (Lycosidae); actual length, 5–6 mm. (Photos by Kenneth Middleham.)

Another conspicuous predatory species is the large black ground beetle, *Calosoma affine* Chaudoir, often seen running rapidly on the ground in fields or along field edges (fig. 14B). *Calosoma* is a predator of large caterpillars, but does not appear to be a major enemy of any particular species.

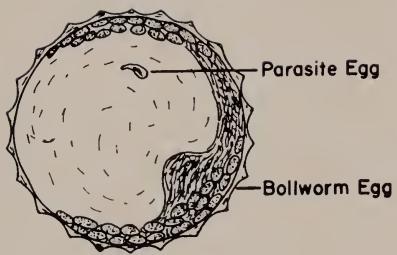
Dragonflies and damselflies often occur in considerable numbers in and about cotton fields. They prey upon a variety of small flying insects, but do not appear to be of great importance.

Certain large wasps of the genus *Polistes* commonly occur in cotton fields (fig. 14C). *Polistes apachus* Sauss. becomes particularly abundant in the desert valleys and probably plays a significant role in control of caterpillars in some cotton fields.

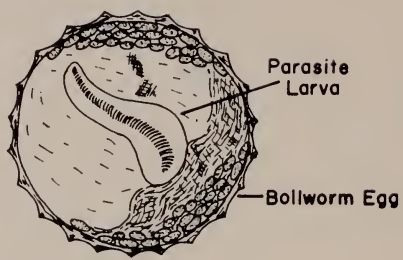
Of the miscellaneous predators, perhaps the true spiders are most important in biological control of many cotton-inhabiting arthropods. Many spider species occur in cotton fields, and they vary greatly in size, appearance, and habit (fig. 15A, B). The most conspicuous are the crab spiders and orb weavers. Spiders attack various hosts, some species being rather indiscriminate feeders and others quite specific. Their feeding habits are probably predominantly beneficial.

Fig. 14. Miscellaneous predators. (A) Praying mantid; actual length, 35–40 mm. (B) Predaceous ground beetle, *Calosoma affine* Chaudoir; actual length, 25 mm. (C) Predaceous wasp, *Polistes apachus* Sauss.; actual length, 9–15 mm. (Photos by Kenneth Middleham.)

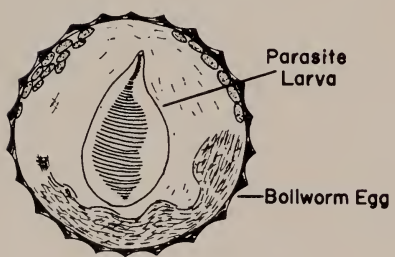
A


Parasite Egg
Bollworm Egg

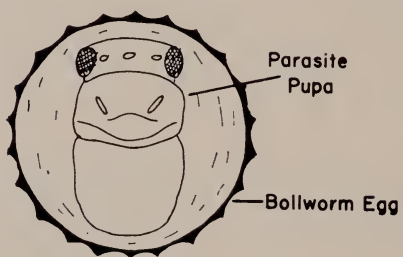
B


Parasite
Larva
Bollworm Egg

C


Parasite
Larva
Bollworm Egg

D


Parasite
Pupa
Bollworm Egg

E

F

PARASITES

Parasites are found in great variety and abundance in California cotton. (See figs. 16–20, and list on pp. 24–26.) They vary greatly in size. For example, the mymarids and trichogrammatids (figs. 16 and 18), which attack the eggs of certain pests, are difficult to detect with the naked eye, while some ichneumonids that attack larger caterpillars are an inch or more in length. Parasite adults generally are much less conspicuous in cotton than are predators, and are therefore not noticed to the same degree. Furthermore, the larval stages occur almost entirely within the parasitized hosts and thus are seldom seen. These are the factors which lead to the general impression that parasites are of lesser importance than predators as natural enemies of cotton pests.

In a typical parasite life history (fig. 16), the adult female searches out the host habitat or the host (the intended victim), then deposits an egg or eggs (or sometimes larvae), upon, within, or near the victim's body. The egg soon hatches into a larva which feeds on the host's tissues and body fluids and eventually kills it. A parasite may be solitary, with a single larva completing its development on or in an individual host, or it may be gregarious, with two or more larvae completing their development on or in a single host. An extreme example of gregarious parasitism is that exhibited by *Copidosoma truncatellum* (Dalm.), a polyembryonic species which parasitizes the cabbage looper. A single egg of *Copidosoma* produces scores of embryos, and several hundred wasps may eventually emerge from a single host larva.

Parasite pupation may occur within or upon the host's dead body, upon the plant, or in the ground litter or soil. Cocoons of certain parasite species are sometimes seen on the cotton plants. Those most commonly observed are generally about the size and shape of a wheat kernel, and they vary in color from buff, green, gray, and white, to yellow. Cocoons of *Hyposoter exiguae* (Vier.) (fig. 17), an important parasite of the cotton bollworm, and cocoons of the cabbage looper and cutworm-armyworm parasites, *Microplitis* spp. and *Apanteles* spp., fall in this group. At times the mummy-like cadavers of looper larvae completely packed with pupae of *Copidosoma truncatellum* are found on cotton leaves. Occasionally the elliptical, mahogany-colored puparia of certain parasitic flies may also be found on the plants. Aphids mummified by the wasp, *Lysiphlebus testaceipes* Cress., are frequently found in large numbers on the undersides of leaves.

Length of the parasite pupation period depends on the species, its physiological state, and weather conditions. Pupation is, of course, terminated by emergence of the free-living adult.

Parasite adults are free-living, and except for their attack on certain insects, are entirely harmless to plant and animal life.

Taxonomy: Thousands of papers deal with the taxonomy of parasitic insects. The following references contain information pertaining to specific papers on various groups. These references are general taxo-

Fig. 16. Left: Life history of a parasitic wasp, *Trichogramma* sp. (A) *Trichogramma* female ovipositing in a bollworm egg. (B) *Trichogramma* egg within a bollworm egg (dorsal view). (C and D) Stages of larval development of *Trichogramma* sp. (dorsal view). (E) Pupa of *Trichogramma* sp. (dorsal view). (F) *Trichogramma* adult emerging from a bollworm egg through hole chewed in the egg shell. (Drawings by C. F. Lagace, after Marchal (1936), Peterson (1930), and Sweetman (1958).)

Fig. 17. The wasp *Hyposoter exiguae* (Vier.), a parasite of bollworm, beet armyworm, and other caterpillars. (A) Adult; actual length, 6–7 mm. (B) Cocoon; actual length, 6–7 mm. (C) Skin and head capsule of the dead host caterpillar. (D) Exit hole made by the wasp in escaping its cocoon. (Photo by Kenneth Middleham.)

nomic works on parasitic groups and do not pertain specifically to parasites occurring in cotton.

Keys to Families: Brues, Melander, and Carpenter (1954), Schlinger and Doutt (1964)

Hymenoptera: Muesebeck, Krombein, and Townes (1951), Krombein (1958)

Diptera: Curran (1934), Townsend (1934–1942)

Biology: Clausen (1940), Sweetman (1958), DeBach (1964)

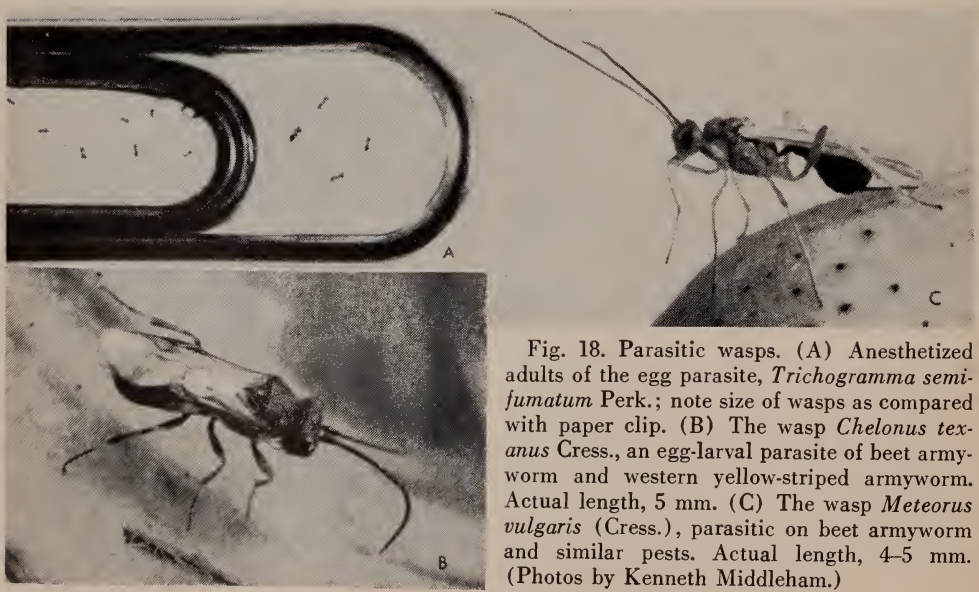


Fig. 18. Parasitic wasps. (A) Anesthetized adults of the egg parasite, *Trichogramma semifumatum* Perk.; note size of wasps as compared with paper clip. (B) The wasp *Chelonus texanus* Cress., an egg-larval parasite of beet armyworm and western yellow-striped armyworm. Actual length, 5 mm. (C) The wasp *Meteorus vulgaris* (Cress.), parasitic on beet armyworm and similar pests. Actual length, 4–5 mm. (Photos by Kenneth Middleham.)

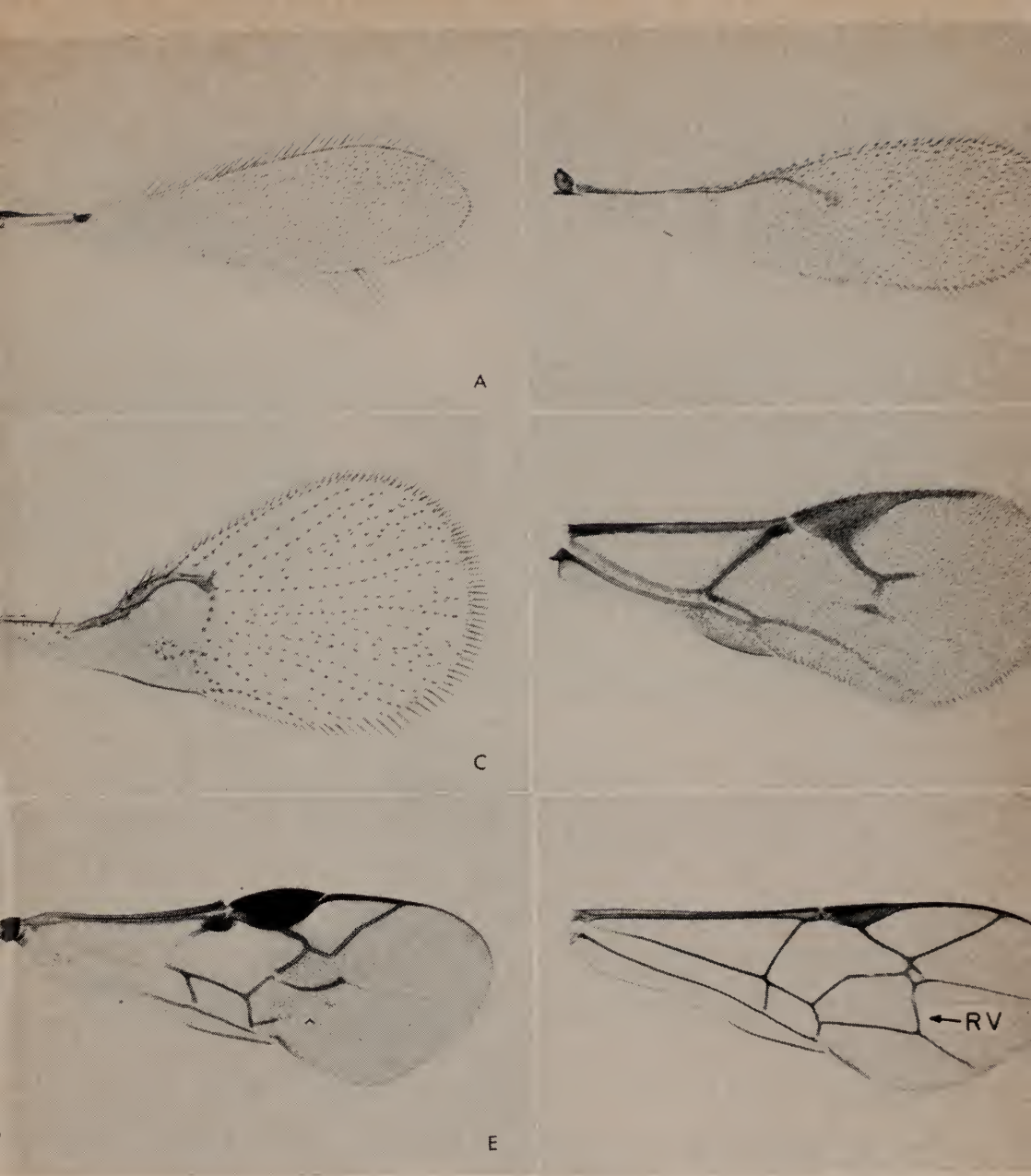


Fig. 19. Wings of parasitic wasps (Hymenoptera). (A) Mymaridae (*Polynema*); (B) Scelionidae (*Telenomus*); (C) Trichogrammatidae (*Trichogramma*); (D) Aphidiidae (*Lysiphlebus*); (E) Braconidae (*Chelonus*); (F) Ichneumonidae (*Hyposoter*). The extra recurrent vein (RV), which is present in most ichneumonids, makes them easily distinguishable from braconids. (Photos by Frank Skinner.)

Fig. 20. Parasitic flies. (A) *Eucelatoria armigera* Coq., an important parasite of the bollworm. Actual length, 6.5 mm. (B) *Archytas californiae* Walk., a large fly parasitic on the western yellow-striped armyworm. Actual length, 11.5 mm. (Photos by Kenneth Middleham.)

Principal Lepidopterous Pests of Cotton in California and Parasites Known to Attack Them

Pest Species: Beet armyworm, *Spodoptera exigua* (Hbn.)

Parasites

Apanteles laeviceps Ashm. (Hymenoptera, Braconidae)
Apanteles marginiventris (Cress.) (Hymenoptera, Braconidae)
Chelonus texanus Cress. (Hymenoptera, Braconidae)
Meteorus vulgaris (Cress.) (Hymenoptera, Braconidae)
Campoletis argentifrons (Cress.) (Hymenoptera, Ichneumonidae)
Hyposoter exiguae Vier. (Hymenoptera, Ichneumonidae)
Melanichneumon rubicundus (Cress.) (Hymenoptera, Ichneumonidae)
Therion californicum (Cress.) (Hymenoptera, Ichneumonidae)
Trichogramma spp. (Hymenoptera, Trichogrammatidae)
Achaetoneura archippivora (Will.) (Diptera, Tachinidae)
Eucelatoria armigera (Coq.) (Diptera, Tachinidae)

Pest Species: Cabbage looper, *Trichoplusia ni* (Hbn.)

Parasites

Apanteles glomeratus (L.) (Hymenoptera, Braconidae)
Apanteles marginiventris (Cress.) (Hymenoptera, Braconidae)
Microplitis brassicae Mues. (Hymenoptera, Braconidae)
Hyposoter exiguae (Vier.) (Hymenoptera, Ichneumonidae)
Copidosoma truncatellum (Dalm.) (Hymenoptera, Encyrtidae)
Trichogramma spp. (Hymenoptera, Trichogrammatidae)
Archytas californiae Walk. (Diptera, Tachinidae)
Eucelatoria armigera (Coq.) (Diptera, Tachinidae)
Voria ruralis (Fall) (Diptera, Tachinidae)
Winthemia quadripustulata (F.) (Diptera, Tachinidae)
Sarcophaga spp. (Diptera, Sarcophagidae)

Pest Species: Cotton bollworm (corn earworm), *Heliothis zea* (Boddie)

Parasites

Apanteles marginiventris (Cress.) (Hymenoptera, Braconidae)
Apanteles militaris (Walsh) (Hymenoptera, Braconidae)
Chelonus texanus Cress. (Hymenoptera, Braconidae)
Campoletis argentifrons (Cress.) (Hymenoptera, Ichneumonidae)
Hyposoter annulipes (Cress.) (Hymenoptera, Ichneumonidae)
Hyposoter exiguae (Vier.) (Hymenoptera, Ichneumonidae)
Therion californicum (Cress.) (Hymenoptera, Ichneumonidae)
Spilochalcis igneoides (Kirby) (Hymenoptera, Chalcididae)
Trichogramma spp. (Hymenoptera, Trichogrammatidae)
Prospaltella spp. (Hymenoptera, Aphelinidae)
Achaetoneura archippivora (Will.) (Diptera, Tachinidae)
Eucelatoria armigera (Coq.) (Diptera, Tachinidae)
Gonia capitata (DeGeer) (Diptera, Tachinidae)
Winthemia quadripustulata (F.) (Diptera, Tachinidae)

Pest Species: Cotton leaf-perforator, *Bucculatrix thurberiella* Busck

Parasites

Apanteles bucculatricis Mues. (Hymenoptera, Braconidae)
Cirrospilus spp. (Hymenoptera, Eulophidae)
Closterocerus utahensis utahensis Crawf. (Hymenoptera, Eulophidae)

Pest Species: Saltmarsh caterpillar, *Estigmene acrea* (Drury)

Parasites

Therion spp. (Hymenoptera, Ichneumonidae)
Trichogramma spp. (Hymenoptera, Trichogrammatidae)
Exorista larvarum (L.) (Diptera, Tachinidae)

Pest Species: Western yellow-striped armyworm, *Prodenia praefica* Grote

Parasites

Apanteles marginiventris (Cress.) (Hymenoptera, Braconidae)
Chelonus texanus Cress. (Hymenoptera, Braconidae)
Meteorus vulgaris (Cress.) (Hymenoptera, Braconidae)
Campoletis intermedius (Vier.) (Hymenoptera, Ichneumonidae)
Nepiera marginata (Prov.) (Hymenoptera, Ichneumonidae)
Hyposoter exiguae (Vier.) (Hymenoptera, Ichneumonidae)
Pterocormus difficilis (Cress.) (Hymenopteria, Ichneumonidae)
Therion californicum (Cress.) (Hymenoptera, Ichneumonidae)
Trachysphyrus tejonensis tejonensis (Cress.) (Hymenoptera, Ichneumonidae)
Archytas californiae Walk. (Diptera, Tachinidae)
Eucelatoria armigera (Coq.) (Diptera, Tachinidae)
Phorocera claripennis (Macq.) (Diptera, Tachinidae)
Aphiochaeta spp. (Diptera, Phoridae)

MASS OR PERIODIC RELEASE OF BENEFICIAL INSECTS AS A PEST CONTROL MEASURE

Growers have attempted to control various pests by means of mass or periodic release of certain beneficial insects, such as the convergent lady beetle (*Hippodamia convergens*), wasps of the genus *Trichogramma*, lacewings (*Chrysopa* spp.), and even praying mantids. Of these natural enemies, *H. convergens* and *Trichogramma* have been most widely used.

Convergent Lady Beetle. Mass release of mountain-collected convergent lady beetles into lowland crops to control various pests is of little or no value. When beetles of this species are collected during winter months, stored until spring, and then released, they invariably fly considerable distances from the release point even when ample food exists there (Davidson, 1924). If *H. convergens* (fig. 10A) is collected from mountain aggregations during the summer and released in lowland crops, the beetles often remain in the area of release, but feed very little because they are dormant (Hagen, 1960; DeBach and Hagen, 1964).

If the grower is considering buying *H. convergens*, he should inquire where the beetles were collected. Species of *Hippodamia*, including *H. convergens*, collected while active in crops (in contrast to aggregations), are usually reproductively active and may feed voraciously. However, the effectiveness of releases of such beetles has not been tested.

Trichogramma. Mass or periodic release of *Trichogramma* is a potentially useful control technique. The wasps are capable of destroying lepidopterous (moth and butterfly) eggs and the technique has had positive results against some pests in certain areas (DeBach and Hagen, *in* DeBach, 1964). However, from what is now known in California, it is impossible to recommend either for or against mass release of *Trichogramma* as an effective pest control measure in cotton. It is hoped that future research will enable us to make recommendations.

ACKNOWLEDGMENTS

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